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PLANNING OF THE DISTRICT HEATING SYSTEM IN COPENHAGEN FROM AN ECONOMIC PERSPECTIVE COMPARING ENERGY-SAVINGS VERSUS FOSSIL-FREE SUPPLY

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ABSTRACT

The Danish government has adopted a long-term energy policy of being independent of fossil fuels by 2050, and that the energy supply for buildings should be independent of fossil fuels by 2035. Therefore, urgent action is needed to meet the requirements for the future energy system. One way of becoming independent of fossil fuels is to energy upgrade the existing building stock and change the energy supply to renewable energy sources. A sustainable way of providing space heating (SH) and domestic hot water (DHW) to buildings in densely populated areas is through the use of district heating (DH). This paper is a theoretical investigation of the DH system in Copenhagen, where heat supply is compared to heat savings in buildings from an economic perspective. Supplying the existing building stock with heat from renewable energy supply technologies e.g. low temperature district heating (LTDH) from geothermal heating plants, may lead to oversized heating plants that are too expensive to build compared to implementing energy savings. Therefore reducing heat demand of existing buildings before investing in supply capacity will save society half the investment, indicating the importance of carrying out energy savings now.

INTRODUCTION

The Danish government has adopted a long-term energy policy of being independent of fossil fuels by 2050, and that the energy supply for buildings should be independent of fossil fuels by 2035. Therefore, urgent action is needed to meet the requirements for the future energy system. [1],[2]. The solution is to combine energy savings and renewable energy supply in an optimal way. The European building stock account for about 40 % of the overall energy use [3]. In order to reduce this energy use there is a need of reducing the energy use of the existing building stock, increase energy efficiency and converting the present heat supply from fossil fuels to renewable energy sources.

The design of new low energy buildings has been in focus throughout the recent years and much research has been carried out in order to design optimized buildings from an energy perspective [4]-[8]. However, only 1% of the building stock today is newly constructed as low-energy buildings, which underlines the importance of looking into the existing building stock, where the potential for energy savings is large [9]-[12]. Investigations have shown that the energy consumption can be reduced with about 50-75%[10]-[14], but it takes significant investment costs to reach very low levels of energy consumption [10]. However, since the existing buildings will remain for many years yet to come, it is an unavoidable factor to deal with

The future energy system will have to be based solely on renewable energy sources, which is a huge challenge for the society. It will have to be based on well coordinated interacting energy supply systems where a list of different renewable energy technologies has to interact and balance in a way that will ensure a system with security of supply.

A sustainable way of providing SH and hot water to the buildings in dense populated areas is by the use of DH [15]. In many countries DH systems are already established, but they, as for the remaining energy supply system, face new challenges in the future. In countries like China, U.S.A, Iceland, and Turkey [16] a large share of the DH supply is based on geothermal, whereas in Denmark, Sweden, and Finland the DH supply mainly comes from combined heat and power generation plants (CHP) [16]. The DH systems will have to be converted from the present supply technologies based on fossil fuels into 100 % renewable energy sources. Different resources such as biomass, geothermal, sun, waste, heat pumps, and surplus heat from the industry and CHP etc. can be considered in regards to convert to a fossil free supply system. In Denmark some CHP plants have been converted into biomass and large solar and geothermal heating plants for DH have already been established. Among newly developed geothermal heating plants in Denmark can be mentioned, Dronninglund, Sønderborg, and Viborg [17].

The DH system currently operates with temperatures of 80°C/50°C. If the DH system is converted into low-temperature DH (60°C/30°C), the heat-losses from the network will be reduced and the heat supply from renewable sources will be more suitable for the system. The geothermal water under Copenhagen can be drawn at a temperature on 73°C [17], so heat pumps will not be needed to elevate the temperature of the water. This will save on electricity and avoid peak loads in the electrical supply system, which will be more fluctuating and vulnerable to peak loads since it will be based on renewable energy sources, mainly wind power.

This paper investigates different scenarios of the future DH system taken into account energy savings and the conversion of the fossil fuel supply technologies into renewable supply technologies. The approach to the investigation is to state the economical consequences of different energy planning scenarios when it comes to the future DH system. The approach is very general and the objective is to give an overall picture of economical consequences by following different energy planning strategies. Details of the individual heating plants and locations of them are neglected and further detailed investigations will have to be carried out if a complete detailed picture has to be drawn. Furthermore simplified assumptions are made and there are details that will have to be investigated further.

Waste heat from the industry could be used in combination with either geothermal or solar heat, but from [20] the potential has been estimated to be low (3%) in the area of Copenhagen since the industry sector is small, and is therefore neglected in this investigation. This paper looks into the implementation of geothermal supply for the future DH system together with waste for incineration. Solar thermal plants with storage or heat pumps would be other possible future solutions, but are not the focus in this investigation.

THE MODEL

Approach

Due to the planned future energy policy, coal will have to be phased out in 2030 [1]. According to the Heat Plan of Copenhagen [18] coal will already have to be phased out in 2025, which have been the basis of this investigation. Additionally it is assumed that biomass will be available until 2040 after which it will descend to the transportation sector that will have to be fossil free in 2050 [1]. It is assumed that the transportation sector will be willing to pay more for the biomass resource in the future, implying that other renewable energy sources will have to be used. Furthermore research has found that Europe will have a biomass potential of only 15-16% of the total primary energy demand in 2030 [19]. This will result in that biomass will have to be imported from 3rd world's countries, which is not preferable and not considered a long term sustainable solution. The biomass is better used locally in order to develop sustainable energy sectors in 3rd world's countries, and to avoid dependency, which is one of the main concerns today regarding fossil fuels.

In order to use renewable energy sources in an efficient way, LTDH should be considered. LTDH has been object for investigation recently and are among others studied in [21]-[28]. When the heating demand in buildings are decreased to low levels the possibility of LTDH becomes an option, since the need of SH will decrease and the peak loads will to a larger extend be "cut off". It is found from [28] that low temperature DH is possible in most hours of the year in existing buildings. The period with very cold climate conditions require an increase in the temperatures, which is assumed to be possible in the waste incineration plants. Supplying water to the transmissions lines with high temperatures from the incineration plants and mixing it with the colder geothermal water in the local DH plants, it is assumed that the temperatures will be able to cope with the heating demand under cold climate conditions. When LTDH is implemented the problematic of legionella has to be considered regarding the DHW. Studies have shown that the legionella problem can be avoided as long as the temperatures are above 50℃ [21], which implies a local boosting of the water temperature in the buildings e.g. by the use of flat stations. Additionally, recent research in Sweden has shown good results by the use of UV-sterilization [29],[30].

Present heat demand and potential for conversion of individual natural gas heated buildings

The present DH network in Copenhagen area consists of three waste incineration plants plus four CHP-plants distributed in a geographical area as shown in Figure 1. The supply area includes the western CHP plants (VEKS) and the central CHP-plants (CTR) in the Copenhagen area. The fundamental basis of this investigation is based on the DH system as it is today, and does not include the entire Copenhagen area at the moment.

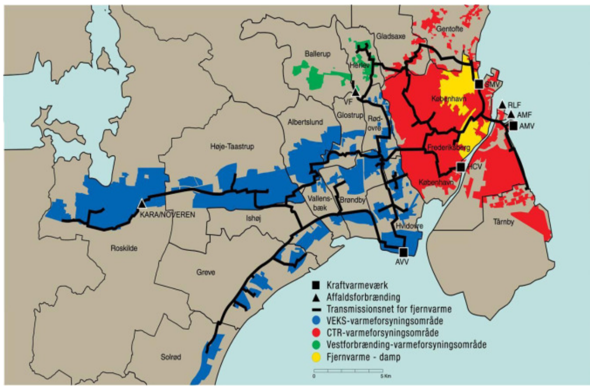

Fig. 1 Map of existing DH network in Copenhagen area. [31]

The total heat demand (2010) of the entire area is 35 PJ/year with a peak load on 2500 MW[31]. The overall net losses are assumed to be 15 % and 8 % of the yearly production with traditional DH and low temperature DH respectively [32],[33]. It is assumed that the DHW demand is 400MW constantly over the year with the exception of the summer period where buildings are expected to use less water due to vacations.

An analysis of the potential of converting individual natural gas users into DH has been carried out [31],[32],[33]. A potential on 10 PJ has been found as a realistic amount within a geographical possible area of conversion [33]. This implies a total yearly consumption on 45 PJ/year and a peak load of about 3200 MW assuming the same increase in percentage from present (2010). Furthermore it is assumed that the DHW-consumption increases with the same tendency as the conversion of the natural gas users into DH takes place.

Energy renovations

As a simplification it has been assumed that a decrease in yearly heat demand on 65%, correspond to a decrease in the power loads on 65%. This simplification is based on simulations made for a low-energy house and an existing building [28], and the ratio of total heat demand over the peak load has been compared. This simplification contains certain errors and will have to be investigated further.

Scenarios

Calculations on three different possible future scenarios are carried out and sensitivity analyzes on the amount of waste for incineration in the future are done. The main calculations are carried out assuming a decrease in the amount of waste on 1/3 in 2070 compared to today.

Reference scenario – No energy renovation but only natural replacement of the existing building mass with new buildings.

This scenario represents a fundamental scenario of what will happen if nothing is done to reduce the heat consumption until 2070. In consequences of that no renovations are done in the existing building mass the buildings will over time dilapidate and be replaced with new buildings. According to [10] a heat reduction of around 50 % corresponds to that the existing buildings will reach an energy level corresponding to what is required from new buildings today in the Danish Building Regulations 2010 [34]. It is assumed that 1% of the existing building mass is replaced with new buildings a year, implying a yearly decrease in the heat demand on 0.5% of the building mass the year concerned.

Scenario 1 – Accelerated energy renovation from 2030-2070

Scenario 1 represents the case where no heat savings are carried out in the near future. The DH supply will be converted from fossil fuels to biomass on the CHP-plants and the prices will remain unchanged. No energy savings are carried out due to pour economy and no legislation or requirements here upon. Only the natural replacement of the building mass with new buildings on 1% per year is undertaken. The biomass will be phased out between 2030 and 2040 after which it will be moved to the transportation sector. Geothermal plants are established in order to cover the remaining nearly unchanged heat demand and the investment in geothermal energy will result in increased prices for DH. Deep energy renovation are carried out and the heat demand decreases with 65 % from 2030-2070, implying a decreased heat supply. The coefficient of utilization will decrease and the prices will rise further.

Scenario 2 – Accelerating energy renovations from today

Scenario 2 represents the case where heat savings are carried out from today. The DH will be converted to biomass and phased out between 2030 and 2040 as for the first scenario, but energy savings are carried out from today until 2040 implying a decrease in the heat demand. The investment in Geothermal heat supply plants are thereby decreased significant.

Economics

In order to calculate the economical consequences for the society for each of the scenarios, simple economical calculations have been carried out. The real interest rate is not considered, which in reality makes the costs higher than indicated here. Estimated costs of investment, maintenance and operating cost are included for geothermal heat and for the DH net. The costs related to the fossil fuels and biomasses are neglected since they are nearly the same in all scenarios. Furthermore it is assumed that the waste in the future will be considered a resource that will be priced, but since the price on heat will be based mainly on the investment in geothermal plants and the coefficient of utilization, the price on waste will be similar. The cost for the reference scenario will be based solely on supply whereas the costs for scenario 1 and 2 furthermore are based on the energy renovation, implying that they will be added to the supply price.

Geothermal investment cost

The investment cost for geothermal is estimated to be 1.6 mil €/MW for a geothermal plant on 135 MW [18],[31],[37]. Around half of the capacity (70MW) comes from geothermal heat. From other sources [35],[36] an investment cost on 1.7 mil €/MW is found. Assuming LTDH implying that there will be no need of heat pumps the investment in geothermal is assumed to be approximately
$2.7\ mil\ €/MW.\quad (1.6\ mil\ €/MW \cdot 2 = 3.2\ mil\ DKK/MW.$ The cost will be around the double, but due to economy of scale it is assumed to be slightly lower $\approx 2.7\ mil\ DKK/MW$).

Operating and maintenance cost

The price for operation and maintenance cost (O&M) is difficult to estimate since it varies depending on various factors and conditions. The O&M-cost is assumed to be 6.3 €/MWh, based on [37].

DH network - Investment in new capacity

According to [37] the investment cost for installing new pipelines in a new DH area with a yearly heat demand on 38,000 MWh is about 10.7 mil €, resulting in a unit price on 282 €/MWh. This fixed asset investment is very sensitive to both the density and the accessibility of the area. Hence a unit price of 302€/MWh is assumed [37].

DH-network - Operating and maintenance cost

The O&M cost is assumed to be 2 €/MWh [36].

Energy renovation costs

According to [10] which is based on the entire building stock in Denmark (dwellings) the cost of saving 102 PJ/year corresponding to energy savings on 65% is 51 Mil €. This result in a unit price per saved petajoule of 8.3 Mil €/PJ, based on saving in 60 years.

Assumed lifetimes

Geothermal:	40 years
DH network:	60 years
Renovations of dwellings:	60 years

Costs

The investment cost for geothermal is found based on the needed capacity in the different scenarios, and O&M-costs are found based on the total geothermal heat production during the period in question (40 years). The investment cost for the DH network is based on the potential for converting natural gas costumers into DH corresponding to 10 PJ. O&M-cost is calculated based on the total heat production throughout the period in question (60 years). The total costs are:

$$\mathrm{Costs}_{\mathrm{Total}} = \mathrm{Invest}_{\mathrm{Geo}} + \mathrm{O\&M}_{\mathrm{Geo}} + \mathrm{Invest}_{\mathrm{DH}} + \mathrm{O\&M}_{\mathrm{DH}}$$

The unit price for supply energy is calculated as:

$$\mathrm{Unit\ Cost}_{\mathrm{Supply}} = \frac{\mathrm{Cost}_{\mathrm{Total}}}{\mathrm{Production}_{\mathrm{Total\_Geo}}}$$

The total costs for the supply throughout the entire period in question are:

$$\mathrm{Total\ Cost}_{\mathrm{Supply}} = \mathrm{Unit\ Cost}_{\mathrm{Supply}} \cdot \mathrm{Production}_{\mathrm{Total\_DH}}$$

In scenario 1 and 2 the total cost for supply is dependent on the decrease in heat demand, implying that the cost for carrying out energy renovation has to be added to the supply price:

$$\mathrm{Cost}_{\mathrm{Savings}} = \mathrm{US} \cdot \mathrm{ES}$$

US is cost of saving one unit of energy
ES is the energy savings in the period in question

Table 1 shows the economical calculations for each scenario.

RESULTS AND DISCUSSION

Reference scenario

The reference scenario represents the case where no accelerated energy renovations are carried out. Figure 2 shows the peak load and the distribution of resources. The priority of the utilization of the resources is 1. Waste for incineration; 2.Geothermal; 3. Biomass; 4. Fossil fuels. As seen from the figure the heat demand is increasing until 2035, due to the conversion of natural gas areas to DH. Simultaneously the existing building mass is replaced with new buildings decreasing the heat demand with 0.5% per year. The figure shows that it is needed to invest in a capacity of 2,800MW geothermal heat.

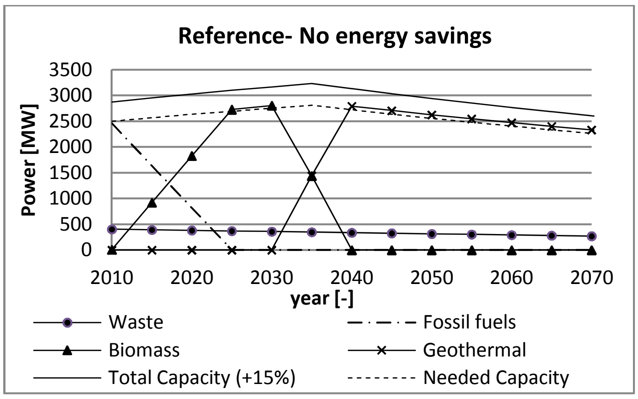

Fig. 2 Peak load for the reference scenario, where no accelerated energy renovations are carried out.

The yearly production of the different supply technologies until 2070 are seen in figure 3. As seen the geothermal heat production is peaking in 2040 with 32 PJ after which it decreases with 13% up until 2070. The total geothermal production in the entire period is 1100 PJ.

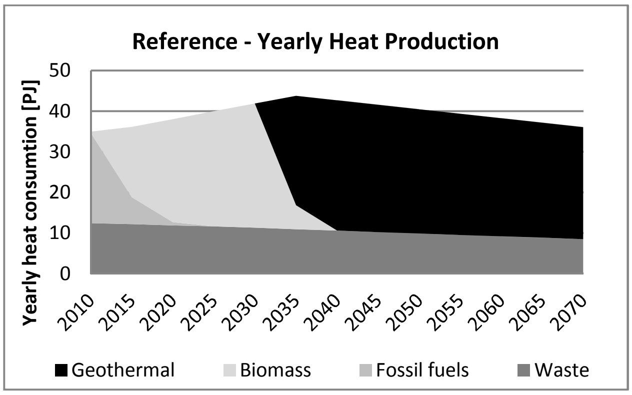

Fig. 3 Yearly heat production for the reference scenario, where no accelerated energy renovations are carried out.

Scenario 1

Scenario 1 represents the case where accelerated energy renovations are carried out from 2030. Figure 4 shows the peak load and the distribution of the supply technologies. As seen from the figure the heat demand is likewise the reference scenario peaking in 2030 after which it decreases. The investment in geothermal capacity is seen to be 2,500 MW, which is slightly lower compared to the reference scenario due to the accelerating energy renovations.

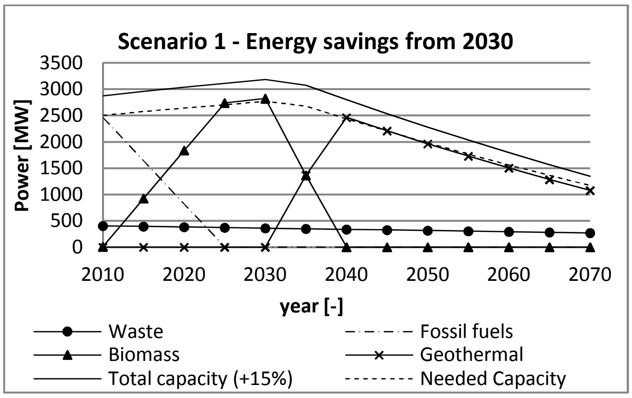

Fig. 4 Peak load for scenario 1 – accelerating energy renovations from 2030.

Figure 5 shows the yearly production of the different supply technologies from 2010-2070. The geothermal production peaks in 2040 with 28 PJ. Due to the accelerating energy renovations the heat demand decreases from 2030 up until 2070 resulting in the coefficient of utilization drops significantly. The production of geothermal heat decreases with 60 % up until 2070 and the total geothermal heat production within the entire period is 780 PJ.

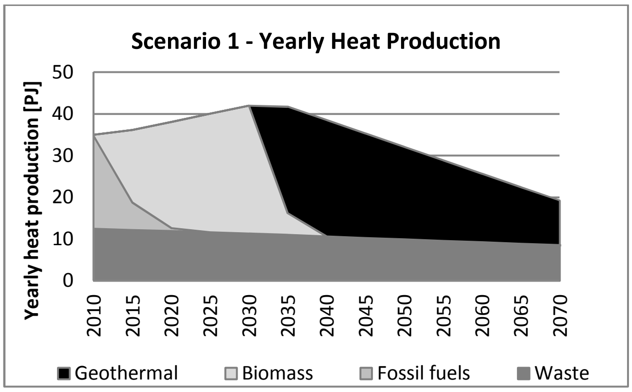

Fig. 5 Yearly heat production for scenario 1 - accelerating energy renovations from 2030.

Scenario 2

Scenario 2 represents the case where accelerated energy renovations are implemented already from today. Figure 6 shows the peak load and distribution of the different supply technologies. The total heat demand is decreasing throughout the entire period in question despite the conversion of the 10PJ. This implies that the investment in geothermal capacity is reduced to 1,200 MW corresponding to a reduction of 60% compared to the reference scenario, and 45% compared to scenario 1.

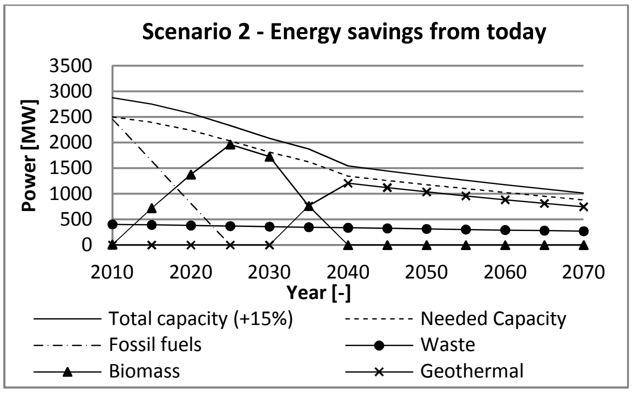

Fig. 6 Peak load for Scenario 2 – accelerated energy renovations from today.

Figure 7 shows the yearly heat production of the different supply technologies until 2070. As seen the geothermal heat production peaks with 16 PJ, which is 50% less compared to the reference scenario and 43% less compared to scenario 1. The geothermal production decreases with around 30% by 2070 compared to the year of peak. The total geothermal heat production throughout the entire period is 484 PJ.

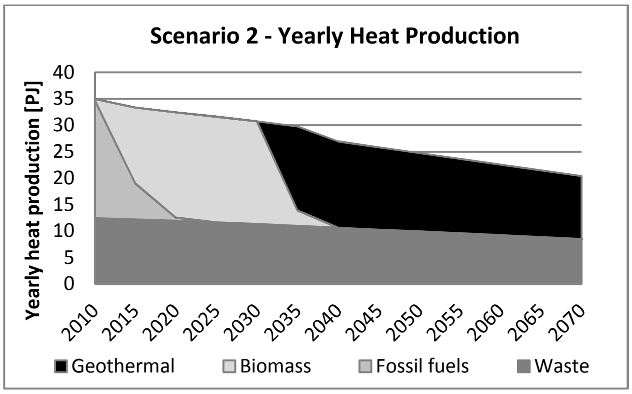

Fig. 7 Yearly heat production for Scenario 2– accelerated energy renovations from today.

ECONOMY

Table 1 shows the estimated costs for each of the scenarios. The total cost for the society is about 25 billion € if no accelerated energy renovations are carried out, but future investment exclusively focus on supplying heat in order to meet the future heat demand. If the accelerated energy renovations are implemented when investment in supply capacity already has taken place (scenario 1) it is seen that it is more costly for the society with about 3 billion € compared to the reference scenario, implying a total price on about 28 billion €. In this scenario the heat demand are reduced after the investment implying that the coefficient of utilization is decreased significant, which is very costly. On the other hand, it is seen that if accelerated energy renovations are implemented already from today (Scenario 2), resulting in a reduced heat demand when the investment in supply capacity takes place, it will save the society for about 1 billion € compared to the reference scenario and about 4 billion € compared to scenario 1.

This stresses the importance in carrying our energy renovation at the right time and thereby reducing the heat demand before investment in supply capacity takes place. As seen supplying heat to an unchanged heat demand compared to implementing energy renovations from today seems to not have significant different consequences. But reducing heat demand seems to be slightly more cost optimal for the society and furthermore, it should be taken into consideration that the peak load will be reduced, creating more stable supply conditions, which is very valuable in the future energy system. Furthermore it will ensure an added value of the building stock.

Table 1 The total cost for each scenarios

		Reference	Scenario 1	Scenario 2
Geothermal				
Unit price for fixed asset investment	[mil €/MW]	2.68	2.68	2.68
Capacity	[MW]	2793	2464	1207
Total price for fixed asset investment	[mil €]	7498	6614	3241
Unit price for O&M - costs	[mil €/MW]	2	2	2
Total O&M - costs	[mil €	1937	1463	947
DH-net				
Unit price for fixed asset investment	[€/MW]	302	302	302
Converted potential (10PJ)	[MWh]	2777778	2777778	2777778
Price for expansion of DH-net	[mil €]	839	839	839
Unit price for O&M - costs	[mil €/PJ]	0.56	0.56	0.56
Total O&M - costs	[mil DKK]	1341	1192	933
Heat production				
Total DH -production in 60 years	[PJ]	2379	2114	1656
Geothermal production in 40 years	[PJ]	1110	838	543
Total costs	[mil €]	11616	10108	5960
Unit price for supply	[mil €/PJ]	10.46	12.06	10.98
Total supply price in 60 years	[mil €]	24886	25487	18185
Renovation				
PJ saved by energy renovating (65%)	[PJ]	-	265	723
Unit price for savings	[mil €/PJ]	-	8	8
Price for energy renovation	[mil €]	-	2205	6021
Total price	[Bil €]	25	28	24

SENSITIVITY ANALYSIS

Waste for incineration

A sensitively analysis is carried out analyzing the consequences of increasing amounts of waste for incineration. All assumptions are unchanged except that the amount of waste is reduced with 1/3 up until 2070 compared to the initial conditions. This results in less investment in geothermal capacity. In reality this will require an investment cost in new incineration capacity, which has not been included in the calculations and reservations should be made here upon. The three scenarios already described are investigated. Figure 8 shows the cost for each scenario.

Geothermal heat as first priority

Furthermore a sensitivity analysis of the consequences for using geothermal heat as first priority compared to waste for incineration has been done. This implies that by 2040 there is no more waste utilized in the DH system and can likewise be seen as the scenario where the amount of waste is reduced, because the energy contained in the waste is utilized for other purposes resulting in a minimum contribution to the heat production. The three scenarios already described are investigated, and figure 8 shows the cost for each of the scenarios.

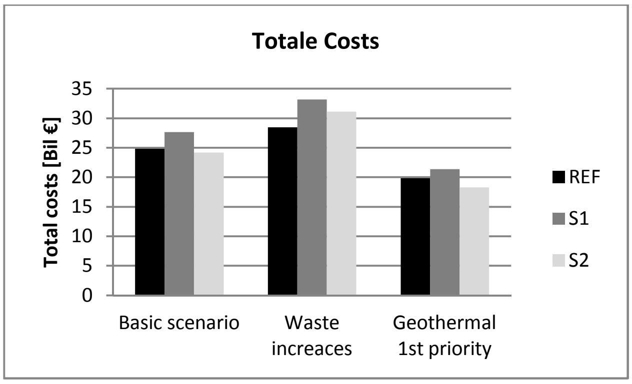

Fig. 8 Comparison between the three scenarios by different assumptions

Figure 8 shows a comparison between the different scenarios and the different sensitivity conditions. As seen scenario 2 represents the cheapest solution for both the basic analyses and the sensitivity analyses of geothermal heat as first priority. In the sensitivity analysis where the waste amounts are increased it is seen that the cheapest solution seems to be the supply-solution. It is expected that the amount of waste is decreased in the future, due to more efficient sorting and more efficient utilization of the energy content for other purposes, implying that either the basic scenario or the geothermal scenario most likely becomes more realistic. As seen from the figure the solution the geothermal as first priority is generally cheaper than the others, due to the fact that the geothermal plants have a higher degree of utilization, which makes it more economically beneficial.

CONCLUSIONS

A simple and very general model analyzing different future energy planning scenarios regarding DH in Copenhagen has been carried out. Furthermore sensitivity analyses of what will happen if the amounts of waste for incineration changes have been done, using different preconditions. It is been found that from an overall economical perspective it is cost beneficial to invest in energy renovations in order to reduced the heat demand before investing in new renewable energy supply technologies for the future DH-system. This will save around half the investment cost in new supply technologies. If the heat demand is reduced after the supply-investment it will be very costly for the society since much capacity will not be utilized. The economical consequences of only focusing on supplying heat for an unchanged demand versus reducing heat demand through energy renovations starting from today, seems to be quite similar. From this investigation it seems to be slightly cheaper and more beneficial to carry out energy renovations, also taken into account the security of supply. Reducing the heat demand results in smaller peak loads and more stable conditions, which is an advantage for the future energy system based on renewable energy resources. This investigation is based on different assumptions that will have to be investigated further, implying certain uncertainties. Though, the conclusion drawn from this investigation indicates that it is important to reduce heat consumption before investing in new capacity.

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